Environmental Monitoring and Assessment (2005) **108:** 279–293
DOI: 10.1007/s10661-005-4327-0

HIKING TRAILS AND TOURISM IMPACT ASSESSMENT IN PROTECTED AREA: JIUZHAIGOU BIOSPHERE RESERVE, CHINA

WENJUN LI*, XIAODONG GE and CHUNYAN LIU
College of Environmental Sciences, Peking University, Beijing, P.R. China
*(*author for correspondence, e-mail: wjlee@pku.edu.cn)*

(Received 4 June 2004; accepted 5 October 2004)

Abstract. More and more visitors are attracted to protected areas nowadays, which not only bring about economic increase but also seriously adverse impacts on the ecological environment. In protected areas, trails are linkage between visitors and natural ecosystem, so they concentrate most of the adverse impacts caused by visitors. The trampling problems on the trails have been received attentions in the tremendous researches. However, few of them have correlated the environmental impacts to trail spatial patterns. In this project, the trails were selected as assessment objective, the trampling problems trail widening, multiple trail, and root exposure were taken as assessment indicators to assess ecological impacts in the case study area Jiuzhaigou Biosphere Reserve, and two spatial index, connectivity and circularity, were taken to indicate the trail network spatial patterns. The research results showed that the appearing frequency of the trampling problems had inverse correlation with the circularity and connectivity of the trail network, while the problem extent had no correlation with the spatial pattern. Comparing with the pristine trails, the artificial maintenance for the trails such as wooden trails and flagstone trails could prohibit vegetation root from exposure effectively. The research finds will be useful for the future trail design and tourism management.

Keywords: circularity, connectivity, protected area, recreation and tourism, trail, trampling problem

1. Introduction

The number of nature reserves in China has increased rapidly, from 34 in 1978 (0.13% of total area) to 1276 in 2000 (12.44% of area). Nature-based tourism, which has received a great deal of attention in recent years (Gray *et al*., 2003), is an effective way to ensure sustainable development for nature reserves. In China, tourism has been developed in about 80% of the nature reserves since the early 1990s. Of the reserves that have developed tourism, 15.9% have more than 100,000 visits annually. It is estimated that total number of visits was about 2.5 million in 1995, and the annual income generated was about US$ 63 million. In the past few years, the number of reserve visitors has increased rapidly as a result of national economic growth. In some nature reserves the average increase rate of reserve visitors from 1995 to 1998 was 87.8%, while during the same period the increase in tourists nationwide was 37.0% for foreign tourists and 10.3% for domestic tourists, respectively (Li and Han, 2001). Obviously, nature reserve tourism is developing more rapidly than other types of tourism.

There is no question that tourism represents one of the most environment-friendly alternatives for economic use of natural resources compared to mining, hunting and farming. However, tourism may also degrade the natural resources upon which it depends especially when management is poor. Tourism not only brings about economic increase but also adverse impacts on the ecological environment. With respect to the impacts caused by tourism, there has been tremendous research works reflected in the publications (Kuss and Morgan, 1980; Liddle and Kay, 1987; Sun and Liddle, 1991, 1993a, 1993b; Hall, 1994; Green, 1998). Australian researchers Sun and Walsh (1998) gave a integrated review of studies on environmental impacts of recreation and tourism. The assessment methods of the past researches could be classified into three classes: experiments, field surveys and questionnaires. Of which, most of the researches were carried out using field surveys, such as Calais and Kirkpatrick (1986), and Sun and Liddle (1993a). The main reason why the field survey approach was popular was due to its lower cost both in finance and time (Sun and Walsh, 1998). In this study, the field survey method was again taken to find the trampling problems caused by visitors.

The hiking trails are linkages between visitors and nature, so they concentrate most of the adverse impacts such as trampling problems caused by visiting (Symmonds *et al.*, 2000). The trampling problems on the trials has been received tremendous attentions in the relevant researches, such as Kuss and Morgan (1980), Liddle (1988, 1991), Kuss and Hall (1991), Sun and Liddle (1991, 1993a, 1993b), Cole and Bayfield (1993), Leung and Marion (1999a), Farrell and Marion (2001, 2002), and Nepal (2003). However, few of them correlated the environmental impacts to trail spatial patterns, which although are usually considered to have effects on hiking experiences (Lynn and Brown, 2003). In this study the connectivity and circularity were taken as indicators to reflect the trail network spatial patterns.

The network connectivity and circularity are originated from graph theory, which is a widely applied framework in geography, information technology and computer sciences. They are primarily concerned with maximally efficient flow or connectivity in networks (Gross and Yellen, 1999). When realized that graph theoretic approaches could provide powerful leverage on ecological processes concerned with connectivity as defined by dispersal, Urban and Keitt (2001) introduced landscape-level graph theory to ecologists, and Bunn *et al.* (2000) used graph theory to exam habitat connectivity for species dispersal. Now the connectivity and circularity have been used extensively in the landscape ecology research (Adriaensen *et al.*, 2003; Taylor *et al.*, 1993) as index to predict the impact of landscape change on a species (Goodwin and Fahrig, 2002), describe habitats and the movement of animal species (Demers *et al.*, 1995; Malanson and Cramer, 1999; Zapata *et al.*, 2003), and indicate corridor conditions act as dispersal routes for some terrestrial animals (Lindenmayer *et al.*, 2000).

Obviously, the connectivity and circularity are related to efficient flow control, capacity expansion, and other relevant works to enhance road networks that are resistant to traffic disturbances (Chen *et al.*, 2002). However, few researches related to trail design for the tourism areas used the connectivity and circularity to reduce the environmental impacts from visitors. In Xiang's research (1996), only variables land suitability, visibility and feasibility (cost estimate) were included, and carrying capacity or network flow which pertain to the spatial patterns were not considered. The few attention paid to the spatial patterns in the trail design have increased the possibilities of trampling problems.

Trampling problems usually result in vegetation loss, soil compaction and erosion, landscape degradation, and others. In order to assess the vegetation loss, the indicators vegetation type (Cole, 1983), vegetation density (Bright, 1986), vegetation root exposure frequency and trail widening (Leung and Marion, 1999a) were applied; while for the assessment of soil compaction and erosion, the indicators soil texture (Bryan, 1977), soil type (Stewart and Cameron, 1992; Jubenville and O'Sullivan, 1987; Summer, 1986), soil moisture (Bayfield, 1986), stoniness (Weaver and Dale, 1978), roughness (Pounder, 1985), incisive treads and trail widening (Leung and Marion, 1999a) were used. The selection of indicators used for the problem assessment depended on the different practical situations and major problems. In our study area Jiuzhaigou Biosphere Reserve (JBR), the indicators trail widening, multiple trail, and root exposure were selected as indicators to assess the trampling problems since the preparatory field surveys showed that they could reflect the major problems there. Another reason why we selected these three indicators was that they were intuitive appearances of the trampling problems, and easy to measure in the field for the managers of the protected areas in the future.

Trail widening was used to measure the trails' extending in width due to visitors' tread, and indicated the extent and frequency of vegetation trampled and soil compacted. Visitors usually wish to make new trail to enjoy more unfamiliar wild nature, so multiple trail was selected to measure the new appeared trails treaded by visitors, and used for indicating the extent and frequency of vegetation trampled, soil compacted, and wild life disturbed. The vegetation roots are often exposure in the trails due to visitors' over use, so root exposure was selected as an indicator to measure the frequency of trampled vegetation.

The trail field survey method was used to obtain the data on trampling problems, and based on which the correlation between the problems (frequency and extent) and the trail characters (spatial patterns and surfaces) was analyzed, respectively.

2. Case Study Area

Jiuzhaigou is located in 103°46′–104°50′E, 32°55′–33°20′N within Sichuan Province, China. It was set as national nature reserve in 1978, listed in the World Heritage in 1992, and approved as the UNESCO World Biosphere Reserve in 1997. There are as many as 4000 kinds of plants, 123 kinds of vertebrates (including more than 50 kinds of rare animals), one kind of fish, 4 kinds of amphibians, 93 kinds of birds, and 21 kinds of beasts in Jiuzhaigou Biosphere Reserve (JBR). The scenic spots and glorious views of this wonderland include majestic and unrivalled emerald Lakes, layer upon layer of waterfalls, colorful forests, snow-topped peaks. The Tibetan culture is also one of the most attractiveness for visitors.

JBR developed its tourism in the early 1980s. Under the background of booming tourism in national wide, JBR attracted more and more visitors during the recent years. The visits increased to 1.2 million in 2003, which was 45 times of 1984 when the tourism was initiated. With the increasing development of tourism, the tourism management and monitoring become urgent and necessary.

As shown in Figure 1, the main road in JBR is a down "Y" shaped along the valley between mountains with a length of 50 km, which is used for green (non-pollution) shuttle bus for visitors moving from one scenic spot to another one. Along the valley, there distribute many lakes, waterfalls, shoal rivers and other scenic spots, around which many wooden, flagstone and pristine trails are designed and constructed for visitors' hiking and enjoying the wonderful scenes.

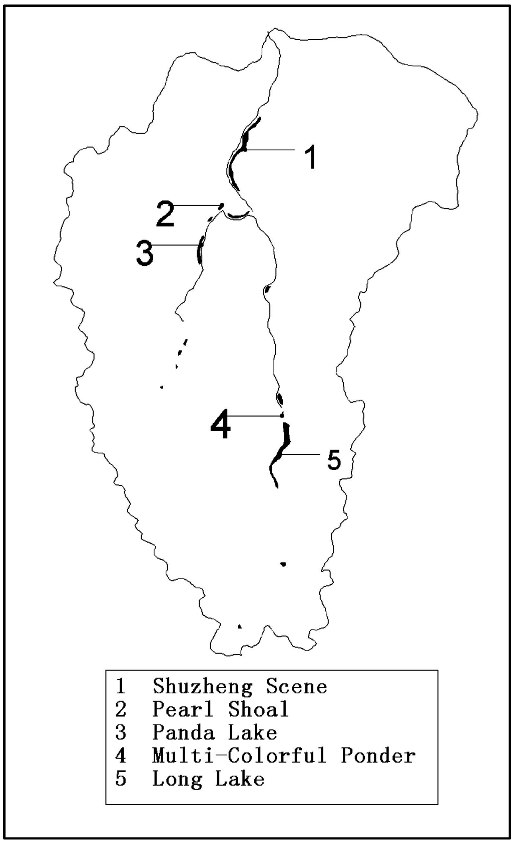

Figure 1. Scenic spots' distributions in JBR.

The hiking trails are designed around attractive scenic spots and connected each other to form a trail network. The bus stops are designed at some trail sections for those visitors who feel tired for hiking and want to take bus to next spot. Most of the visitors entered the reserve in the early morning and spend whole day in the valley, and come back in the evening and live in the outside hotels for one night. Generally they take full advantage of the daytime to visit all the hot spots along the trails.

The total length of these hiking trails is about 10 km, which concentrate most the impacts caused by visitors.

3. Methods

3.1. Assessment factors

The assessment factors, frequency and extent, were assigned to the three indicator to evaluate the impacts caused by visitors.

For the trail widening, the following three assessment factors were employed in each scenic spot: problem frequency (Ftw) = problem times/trail length (times/100 m), problem extent in length (Ltw) = problem length/trail length, problem extent in width (Wtw) = problem width/trail width.

For the problem indicator multiply trail, the problem frequency (Fmt) and problem extent in length (Lmt) were applied; and only the factor of problem frequency was used for assessment of root exposure (Fre).

The problem assessment in the study covered three aspects: the problems in the different scenic spots; the correlation between the problems and the trail spatial patterns; and the problems in the different trail surfaces.

When evaluating the problems in the different scenic spots, the integrated assessment factors were applied for each scenic spot: problem frequency = Ftw + Fmt + Fre, problem extent in length = Ltw + Lmt, problem extent in width = Wtw.

The same integrated assessment factors were used as dependent variables into the linear regression to find the correlation between the problems and trail spatial patterns. For the independent variables, connectivity (γ) and circularity (α), were applied to reflect the trail spatial patterns (Farina, 1998; Forman, 1995).

γ reflects the connectivity of a trail net, which is valued as the ratio of practical number of lines in the network to the possible maximal number of lines shaping the net, as following expression:

$$\gamma = \frac{L}{L_{\max}} = \frac{L}{3(V-2)}$$

where L is the practical number of lines in the trail network in each scenic spot, $L_{\max}$ the possible maximal number of lines shaping the trail network, and V the number of nodes in the network. α is the index used for measuring the circularity of a trail net, which is valued as the ratio of the existing loops to the theoretical maximal loops in the trail net.

$$\alpha = \frac{O}{O_{\text{max}}} = \frac{L - V + 3}{2 \times V - 5}$$

where O is the number of existing loops in the trail net in each scenic spot, O_{max} the possible maximal number of loops shaping the trail net, V the number of nodes in the net.

3.2. Sampling schedule

In the trail problem assessment in JBR, all the trails were selected as assessment objectives, so the statistic bias caused by sample distribution could be avoided (Leung and Marion, 1999b). The total length of trails is 8624.6 m, and it took three researchers 4 days to complete all the field survey. One of the researchers was working in JBR, who was very familiar with the trail situation.

TABLE I
Field survey results for the trail problems in JBR

	Scenic spots							
	Long Lake	Multi-Colorful Pond	Shuzheng Scene			Pearl Shoal		Panda Lake
Trail properties								
Trail ground	Flagstone	Flagstone	Pristine	Wooden	Flagstone	Wooden	Flagstone	Flagstone
Length (m)	511.5	445.5	2837.5	985.5	517.6	401.0	424.0	2502.0
Width (m)	1.5	1.5	0.6	1.0	1.5	1.48	1.45	1.48
Problem indicators								
Trail widening								
Frequency (times)	8	7	–	–	6	–	14	40
Length (m)	173.7	55.5	–	–	43.5	–	194.1	631.8
Width (m)	1.6	3.2	–	–	4.0	–	2.0	1.54
Multiple tread								
Frequency (times)	24	9	12	–	4	–	1	18
Length (m)	217.6	95.4	173.5	–	157	–	5	245
Root exposure (RE)								
Frequency (times)	13	23	165	–	–	–	6	35

3.3. Field survey

Researchers walking along the trails, and recorded the type of trail surface and its length and width in every scenic spot. When encountered the trail problems, stopped and measured the extent of the problems as well as recorded the appearing frequency.

For the problem of trail widening, if the problem length was more than 1 m and the problem width was more than 0.1 m (the normal width of a human's foot), it would be recorded; for the indicator multiple trail, the problem appearing times and problem length would be recorded when it was more than 1 m in the length; and for the root exposure, one problem time was recorded whenever the root exposed on or nearby the trails.

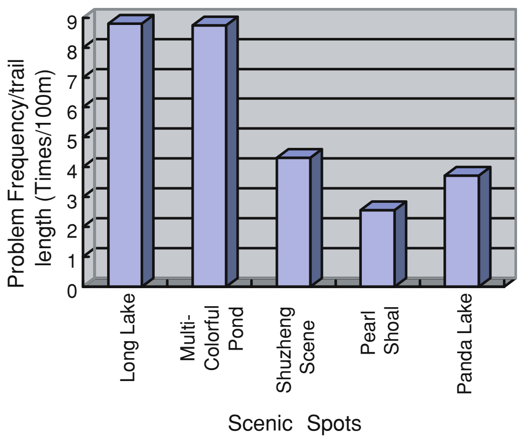

Figure 2. Problem frequency in different scenic spots.

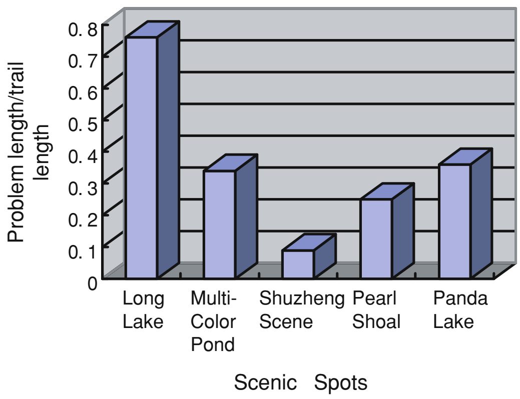

Figure 3. Problem extent in length in different scenic spots.

4. Results

4.1. Problems in different scenic spots

The survey results were listed in Table I. The problem frequency and extent in different scenic spots were shown in Figures 2–4. As shown in Figure 2, the problem frequency (Ftw + Fmt + Fre) in Long Lake and Multi-Colorful Pond was higher than in Shuzheng Scene and Panda Lake, and the lowest frequency was located in Pearl Shoal. As for the problem extent in length (Ltw + Lmt), the highest ratio of the problem trails to the original trail length was located in Long Lake, and Shuzheng Scene was the best situation, as shown in Figure 3. When considering the problem extent in width (Wtw), as shown in Figure 4, the problem was most serious in Shuzheng Scene, and Long Lake, Pearl Shoal and Panda Lake were almost in the same level.

TABLE II
Problem database for different scenic spots in JBR

	Scenic spots				
	Long Lake	Multi-Colorful Pond	Shuzheng Scene	Pearl Shoal	Panda Lake
Trail lines (L)	10	8	9	4	6
Trail nodes (V)	10	6	9	3	6
Connectivity (γ)	0.42	0.33	0.43	0.50	0.50
Circularity (α)	0.20	0.09	0.23	0.67	0.43
Trail widening					
Frequency (times)/trail length (100 m) (Ftw)	1.56	1.57	0.14	1.70	1.60
Problem length/trail length (Ltw)	0.34	0.13	0.01	0.24	0.25
Widening width/trail width (Wtw)	1.07	2.13	2.67	1.38	1.04
Multiple tread					
Problem frequency/trail length (100 m) (Fmt)	4.69	2.02	0.37	0.12	0.72
Problem length/trail length (Lmt)	0.42	0.21	0.08	0.01	0.10
Root exposure					
Problem frequency/trail length (100 m) (Fre)	2.54	5.16	3.80	0.72	1.40
Integrated assessment factors					
Problem frequency/trail length (times/100 m) Ftw + Fmt + Fre	8.80	8.75	4.31	2.55	3.72
Problem length/trail length Ltw + Lmt	0.76	0.34	0.09	0.25	0.36
Problem width/trail length Wtw	1.07	2.13	2.67	1.38	1.04

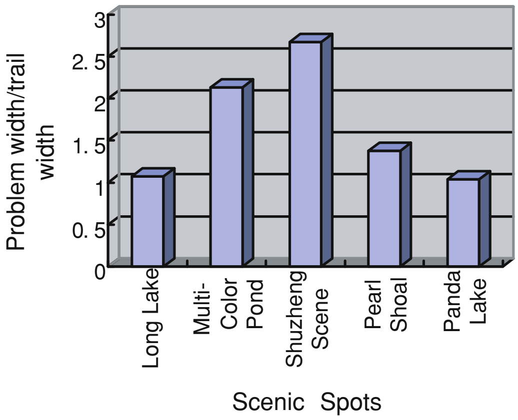

Figure 4. Problem extent in width in different scenic spots.

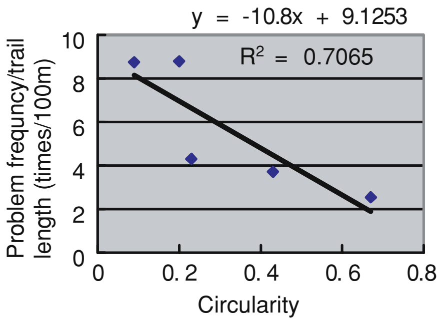

Figure 5. Correlation between problem frequency and circularity.

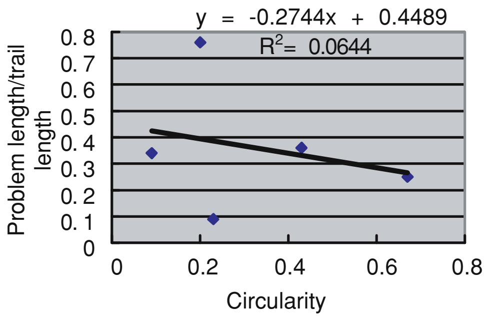

Figure 6. Correlation between problem extent in length and circularity.

4.2. Correlation between problems and trail spatial patterns

For the convenience to evaluate the correlation between trail problems and spatial patterns of the trail network, the integrated assessment factors and the trail connectivity and circularity in each scenic spot were calculated and listed in Table II.

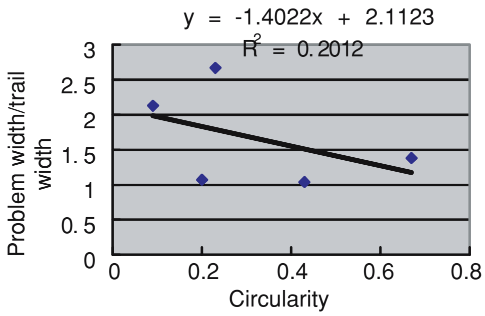

Figure 7. Correlation between problem extent in width and circularity.

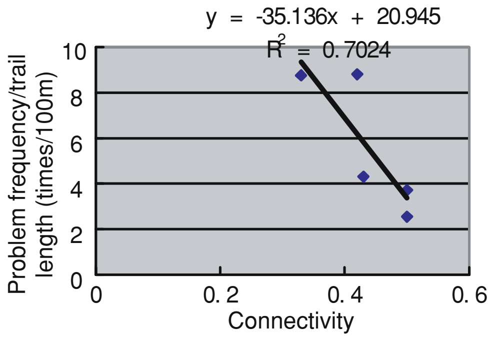

Figure 8. Correlation between problem frequency and trail connectivity.

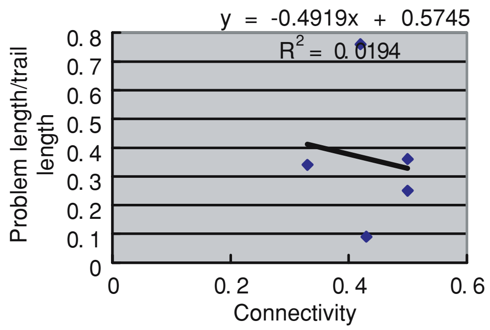

Figure 9. Correlation between problem extent in length and trail connectivity.

As shown in Figure 5, there existed a significant correlation between the problem frequency and the trail circularity, the correlation index R^2 was more than 0.7; while no correlation exited between the problem extent (both in length and width) and the circularity since the correlation R^2 was only 0.0644 and 0.2012 respectively, as shown in Figures 6 and 7.

TABLE III
Problem database for different trail surfaces in JBR

	Trail surfaces		
	Pristine trail	Wooden trail	Flagstone trail
Trail properties			
Length (m)	2837.5	1386.5	4400.6
Width (m)	0.6	1.25	1.5
Problem indicators			
Trail widening			
Problem frequency (times/100 m)	–	–	1.70
Problem extent in length	–	–	0.25
Problem extent in width	–	–	1.04–2.67
Multiple tread			
Problem frequency (times/100 m)	0.42	–	1.27
Problem extent in length	0.06	–	0.16
Root exposure (RE)			
Problem frequency (times/100 m)	8.82	–	1.75
Integrated assessment factors			
Problem frequency (times/100 m) Ftw + Fmt + Fre	9.24	–	2.97
Problem extent in length Ltw + Lmt	0.06	–	0.41
Problem extent in width Wtw	–	–	1.04–2.67

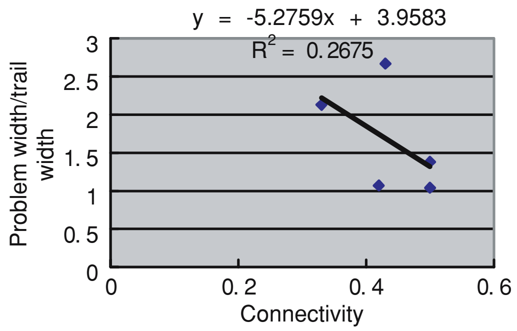

Figure 10. Correlation between problem extent in width and trail connectivity.

The situation was the same when the correlation between problems and trail connectivity was explored. Figures 8–10 showed that the correlation between the problem frequency and the trail connectivity was significant, while there was no correlation between the problem extent (both in length and width) and the connectivity.

4.3. Problem assessment in different trail surfaces

There were three types of trail surfaces in JBR, including pristine, wooden and flagstone trail. The problem frequency and extent were significant different in different trail surfaces as shown in Table III.

According to the integrated assessment factors in Table III, the problems were mostly happened in the pristine trails, the frequency was as high as 9.24 times/100 m, and of which there was 8.82 times/100 m was contributed by root exposure. The problem extent (both in length and width) in the flagstone trails was little bit more serious than in the pristine trails. There was no trail problem in the wooden trails.

5. Conclusions and Discussions

The method of applying trail problem analysis to assess the trail condition for the purpose of tourism management has been used before as mentioned in the introduction (Leung and Marion, 1999a), but the correlation analysis between the trampling problems and trail spatial patterns were firstly proposed in this study.

The trail spatial patterns have great influences on the trampling problems. The case study in JBR showed that the good conditions of circularity and connectivity could reduce the appearing frequency of the trampling problems through guiding visitors moving effectively, so the frequency of trampling problems in the trail network caused by visitors was less than the one-way. That is why there was an inverse correlation between the problem frequency and the trail pattern, as shown in Figures 5 and 8. These finds could be suggestive clues for the future trail spatial pattern design. The study showed that there was no correlation between the problem extent and the trail spatial patterns, as shown in Figures 6, 7, 9 and 10. It could be explained that, comparing with the problem frequency, the problem extent was more depended on user density than the trail spatial patterns. The more visitors, the longer and wider the problem trails.

Although there have been many researches revealed the trail trampling problems, the reasons have rarely been explained, especially in the aspects of the trail design in the spatial patterns. Using the correlation between the problem frequency and the trail spatial patterns, we can explain why the different problem frequency in different scenic spots. Taking this case study as an example, since the circularity in Long Lake and Multi-Colorful Pond was lower (as shown in Table II), the problem frequency appeared in these two spots was higher than others, as shown in Figure 2; while the circularity in Pearl Shoal was the highest, so the problem frequency appeared there was lowest.

Regarding the problems in different trail surfaces, as the above assessment results, the problem frequency was higher in pristine trails, but the problem extent was more serious in the flagstone, and there was no problem in wooden trails. As shown in Table III, the root exposure happened on pristine trails was much more frequent than on the wooden and flagstone trails. It could be thus concluded that the trails artificially covered by wood and flagstone could effectively prohibit the vegetation roots from exposure. However, the survey data showed that the trails paved with flagstone seemed not so effective on reducing the problems of trail widening and multiple trails. These finds could be useful for the future trail construction in the JBR.

Acknowledgments

The project was coordinated by Chinese National Committee for MAB. The administrative bureau of Jiuzhaigou Biosphere Reserve provided great help during the field survey. Sincere thanks must go to Mr. Nianyong Han, the Secretary-General of Chinese National Committee for MAB. Special thanks should go to Zhongfu Zhu, Langga Selang, and Zeren Buqiu, the staffs of Jiuzhaigou Biosphere Reserve. The project is funded by National Natural Sciences Foundation of China (40271032).

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